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PURDUE UNIVERSITY



DEPARTMENT OF EARTH
AND ATMOSPHERIC SCIENCES

TO: Distribution List for Final Report, Contract NAS8-37127
FROM: D.G. Vincent, Principal Investigator *D.G.V.*
DATE: 24 July 1991
SUBJECT: Final Report

Enclosed is a copy of the Final Report, "The South Pacific Convergence Zone and Global-Scale Circulations" which has been prepared for NASA Contract #NAS8-37127 (DSP #520-1397-0419) which was issued to Purdue University. Earlier this month, draft copies of the Report were sent to the Contracting Officer, Mr. John Kaufman, and Dr. Fred Leslie, Chief, Fluid Dynamics Branch, both at MSFC/NASA. They have now given their approval to submit the Report for distribution; thus, it is enclosed.

(NASA-CR-184210) SOUTH PACIFIC CONVERGENCE
ZONE AND GLOBAL-SCALE CIRCULATIONS Final
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Contractor: Purdue Research Foundation
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Title on Contract: South Pacific Convergence Zone and Global-Scale
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Author of Report: Dr. Dayton G. Vincent

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MSFC, AL 35712

1. INTRODUCTORY REMARKS

The original period of this contract was three years beginning 20 July 1987; however, the startup funds were not available until about three months later. In part, for this reason, plus the fact that the PI's support was unused for 6 months while he was on sabbatical leave in Germany during 1989, the contract was extended, at no cost, for an additional year. Thus, the total project period which this report covers is 20 July 1987 - 19 July 1991. The major goals of the research can be classified under three categories: (1) heat and moisture budget studies in the tropics; (2) the role of tropical forcing on subtropical wind maxima in the Southern Hemisphere; and (3) general circulation modeling of low latitude circulations. Research related to the first goal included budget estimates of precipitation, as well as a comparison to rainfall rates observed at numerous island stations. It also included a comparison between observed and satellite estimates of precipitable water. Results and methods used to achieve this goal are given in section 3. Included in the second research goal were diagnostic studies of the intraseasonal oscillation which is known to be an important component of organized tropical convection. Also, the role of extratropical forcing on subtropical wind maxima was examined through the use of Eliassen-Palm (EP) fluxes. Again, results and procedural details are discussed in section 3. To accomplish the third research goal, the GLA general circulation model (GCM) was ported to Purdue University and successfully used in a number of control and experimental runs to investigate the significance of tropical heating on subtropical and extratropical circulation features. As with the first two research goals, results and methodology appear in section 3.

Section 2 provides the documentation of publications, theses, conference preprint papers, and other scientific information relevant to the research results and significant accomplishments achieved under the contract. As a result of the contract, 5 students received their degrees, 8 papers were published in refereed journals, and numerous presentations (including some preprint papers) were given at national and international meetings and seminars. Finally, section 4 gives the conclusions of the sponsored research and offers recommendations for continued and new research. It should be mentioned that we now are completing the first year of our new NASA research grant which includes implementation of some of these recommendations.

2. DOCUMENTATION OF RESULTS

a. Research team

The following is a list of personnel who made scientific contributions to the research contract sometime during its 4-year period:

Dr. Dayton G. Vincent
Dr. Franklin "Pete" Robertson
Dr. Huo-Jin "Alex" Huang
Dr. Deirdre M. Kann
Dr. James W. Hurrell
Dr. Peter Speth

Mr. Mark A. Bourassa

Principal Investigator
scientific collaborator
scientific collaborator
scientific collaborator
former graduate student
scientific collaborator
(Cologne)
current Ph.D. student

Mr. Ken-Chung Ko	current Ph.D. student
Mr. Perry G. Ramsey	current Ph.D. student
Mr. Thomas Sperling	graduate student (Cologne)
Mr. Andreas Fink	graduate student (Cologne)
Captain Keith North, USAF	former graduate student
Mrs. Catherine Pedigo Hurrell	former graduate student
Mr. Stefan Zube	graduate student (Cologne)
Mr. Robb Velasco	B.S. Honors student
Ms. Melinda Hunter	scientific assistant
Mr. Rick Knabb	scientific assistant
Mr. Greg Meffert	scientific assistant
Mr. Douglas Miller	scientific assistant
Ms. Helen Henry	secretary

b. Refereed publications

- Huang, H.-J. and D.G. Vincent, 1988: Active and inactive phases of the South Pacific convergence zone and changes in global circulation patterns: A case study. Beitr. Phys. Atmos., 61, 123-134.
- Robertson, F.R., D.G. Vincent and D.M. Kann, 1989: The role of diabatic heating in maintaining the upper-tropospheric baroclinic zone in the South Pacific. Quart. J. Roy. Meteor. Soc., 115, 1253-1271.
- Hurrell, J.W. and D.G. Vincent, 1990: Relationship between tropical heating and subtropical westerly maxima in the Southern Hemisphere during SOP-1, FGGE. J. Climate, 3, 751-768.
- Pedigo, C.B. and D.G. Vincent, 1990: Tropical precipitation rates during SOP-1, FGGE, estimated from heat and moisture budgets. Mon. Wea. Rev., 118, 542-557.
- Hurrell, J.W. and D.G. Vincent, 1991a: The maintenance of short-term subtropical wind maxima in the Southern Hemisphere during SOP-1, FGGE. J. Climate, 4, (to appear in the September issue).
- Vincent, D.G., K.H. North, R.A. Velasco and P.G. Ramsey, 1991a: Precipitation rates in the tropics based on the Q_1 -budget method: 1 June 1984 - 31 May 1987. J. Climate, 4 (to appear in the October issue).
- Vincent, D.G., T. Sperling, A. Fink, S. Zube and P. Speth, 1991b: Intra-seasonal oscillation of convective activity in the tropical Southern Hemisphere: May 1984 - April 1986. J. Climate, 4, 40-53.
- Hurrell, J.W. and D.G. Vincent, 1992: A GCM case study on the maintenance of short-term subtropical wind maxima in the summer hemisphere during SOP-1, FGGE. (accepted for publication by Quart. J. Roy. Meteor. Soc.)

c. Theses

- Pedigo, C.B., 1988: Precipitation estimates in the tropics by the global heat and moisture budgets during SOP-1, FGGE. M.S. thesis, Department of Earth and Atmospheric Sciences, Purdue University, West Lafayette, IN 47907, 78 pp.
- North, K.H., 1990: Precipitation rate computations in the tropics by the global heat budget technique from 1 June 1984 - 31 May 1987. M.S. thesis, Department of Earth and Atmospheric Sciences, Purdue University, West Lafayette, IN 47907, 68 pp.
- Hurrell, J.W., 1990: Maintenance of short-term subtropical wind maxima in the Southern Hemisphere: Observational and modeling study. Ph.D. thesis, Department of Earth and Atmospheric Sciences, Purdue University, West Lafayette, IN 47907, 160 pp.
- Ko, K.-C., 1990: Baroclinic (shear) and barotropic (mean) kinetic energy study of Southern Hemisphere subtropical wind maxima. M.S. thesis, Department of Earth and Atmospheric Sciences, Purdue University, West Lafayette, IN 47907, 54 pp.
- Velasco, R.A., 1991: Diagnosis of moisture parameters in the tropics using two estimates of precipitation rates from 1 June 1984 - 31 May 1987. B.S. Honors thesis, Department of Earth and Atmospheric Sciences, Purdue University, West Lafayette, IN 47907, 77 pp.

d. Preprint papers

- Miller, D.K. and D.G. Vincent, 1988: An example of estimates of precipitable water derived from NIMBUS-7 SMMR satellite measurements and FGGE upper air data. Third Conference on Satellite Meteorology and Oceanography, January 31 - February 5, 1988, Anaheim, CA, American Meteorological Society, 45 Beacon St., Boston, MA 02108, 70-73.
- Pedigo, C.B., D.G. Vincent and J.W. Hurrell, 1989: Clouds, precipitation and the global heat and moisture budgets during SOP-1, FGGE. Symposium on the Role of Clouds in Atmospheric Chemistry and Global Climate, January 30 - February 2, 1989, Anaheim, CA, American Meteorological Society, 45 Beacon St., Boston, MA 02108, 129-133.
- Ramsey, P.G., 1990: Diagnosis of tropical convection using the ISCCP C1 data set. Fifth Conference on Satellite Meteorology and Oceanography, September 3-7, 1990, London, England, American Meteorological Society, 45 Beacon St., Boston, MA 02108, 285-286.
- North, K.H. and D.G. Vincent, 1991: Precipitation rates in the tropics: June 1984 - May 1987. Seventh Symposium on Meteorological Observations and Instrumentation, January 14-18, 1991, New Orleans, LA, American Meteorological Society, 45 Beacon St., Boston, MA 02108, 189-194.

Hurrell, J.W. and D.G. Vincent, 1991b: Observational and modeling study of the maintenance of short-term subtropical wind maxima in the Southern Hemisphere during SOP-1, FGGE. 19th Conference on Hurricanes and Tropical Meteorology, May 6-10, 1991, Miami, FL, American Meteorological Society, 45 Beacon St., Boston, MA 02108, 422-427.

e. Conference presentations/invited seminars

Miller and Vincent, 1988: Satellite/Oceanography conf.
Hurrell and Vincent, 1989: Global Weather Exp symp., Reading, England
Pedigo and Vincent, 1989: Global Energy/Water Fluxes symp., Reading, England
Pedigo, Vincent and Hurrell, 1989: Clouds in Chm/Clim symp.
Vincent, 1989: Roy. Inst. Meteor., Brussels, Belgium
Vincent, 1989: Inst. Oceanography, Kiel, Germany
Vincent, 1989: Inst. Geophys/Meteor., Cologne, Germany
Ramsey, 1990: Satellite/Oceanography conf., London, England
Hurrell and Vincent, 1991: Hurricanes/Tropical Meteor. conf.
North and Vincent, 1991: Meteor. Observations/Instrumentation symp.

f. Other

Speth, 1988: visited Dr. Vincent at Purdue University.
Vincent, Hurrell and Pedigo, 1988: research visit, MSFC/NASA, Huntsville, AL.
Vincent, 1988: annual research review, MSFC/NASA, Huntsville, AL.
Hurrell, 1989: annual research review, MSFC/NASA, Huntsville, AL.
Vincent, 1990: annual research review, MSFC/NASA, Huntsville, AL.
Speth, 1990: visited Dr. Vincent at Purdue University.
Vincent, 1990: invited participant to ECMWF seminar Reading, England.
Vincent, 1991: annual research review, MSFC/NASA, Huntsville, AL.

3. RESEARCH RESULTS/SIGNIFICANT ACCOMPLISHMENTS

A summary of the more significant results and accomplishments of the research contract are given below, and are discussed according to the three major research goals stated in section 1. The references cited in this section are given in section 2b, d.

a. Heat and moisture budget studies in the tropics

Pedigo, et al. (1989) and Pedigo and Vincent (1990) computed global estimates of precipitation rates between latitudes 30°N-30°S for SOP-1, FGGE using the highly specialized FGGE level III-b analyses from NASA GLA. Precipitation rates were derived as the residual from both the "apparent" heat source (Q_1) and "apparent" moisture sink (Q_2) budgets. Daily values were spatially averaged for several regions, with a focus on the Southern Hemisphere because of our interest in assessing the importance of the South Pacific convergence zone (SPCZ). Time averages were also calculated for two periods (10-24 January and 28 January - 11 February 1979) that were selected because of significant changes observed in the convective activity. In the

first period intense convection was indicated in the SPCZ, with a subsequent lack of activity there in the latter period. During the second period, a buildup of convective activity was noted in the Indian Ocean. Vertical profiles of heating were also presented for each region and comparisons were made between the profile for the SPCZ and convectively active regions investigated elsewhere in previous studies. Finally, precipitable water (W) was computed and compared to results derived from satellite microwave measurements (SMMR), as well as to the budget-produced precipitation patterns.

Results indicated that the heat and moisture budget estimates of precipitation compared favorably. Vertical profiles revealed that maximum convective heating occurred in the middle troposphere and the profile of the SPCZ region compared best with those over the western North Pacific. In general, the largest values of W were observed in the area of lowest outgoing longwave radiation and strongest rainfall rates. Patterns of W from GLA compared well with those from the satellite measurements. In an earlier study (Miller and Vincent, 1988), we had conducted a detailed investigation comparing values of W computed from GLA analyses to those derived from SMMR (21-18 GHz) in the SPCZ region. The values were in good agreement, but GLA values were slightly greater in most cases.

Because of encouraging results from the budget techniques using FGGE data, we embarked on a more general investigation in which routine data (ECMWF analyses) were used to estimate precipitation rates over a 3-year period. Vincent, et al. (1991a) and North and Vincent (1991) applied the Q_1 -budget method and computed monthly mean values of rainfall rates over the tropics from June 1984 to May 1987. Time series for several geographic regions revealed that: (1) the South Pacific convergence zone (SPCZ) had the highest precipitation rates in the Southern Hemisphere; (2) a clear and distinct seasonal cycle was prominent in all regions; and (3) the 1986-87 ENSO event was easily identified, particularly in the TOGA-COARE region. In addition, Hovmoeller diagrams of 5-day running means of Q_1 showed a gradual eastward shift of diabatic heating over the Pacific Ocean which corresponded to the ENSO event of 1986-87. They also showed some evidence of an intraseasonal (40-50 day) oscillation over the western and central Pacific.

b. Role of tropical forcing on subtropical wind maxima in Southern Hemisphere

This research goal was initiated through one of our studies which is discussed by Huang and Vincent (1988). We used GLA Level III-b analyses from SOP-1, FGGE to examine changes in the global-scale circulation features during the period, 10 January - 13 February 1979. In the first two weeks of this period, the South Pacific Convergence Zone (SPCZ) and its convective cloud band were observed to be dominant features of the circulation. Subsequent to 24 January, there were marked changes in the global-scale circulation, particularly in the Southern Hemisphere tropics. Concomitant with these changes was the disappearance of the SPCZ and its cloud band. The primary purpose of the study was to compare some general circulation parameters, which frequently correspond to deep convection, for two 15-day periods: 10-24 January when the SPCZ was very convectively active, and 28 January - 11 February when it was inactive. Distinct changes were seen to occur in the circulation patterns by the end of the first period. One of the more

significant changes from Period 1 to Period 2 was the weakening of the upper level divergent flow in the SPCZ and a strengthening over the southern Indian Ocean. Suggestions were offered regarding mechanisms which might be responsible for the observed changes. In subsequent papers (Robertson et al., 1989; Hurrell and Vincent, 1990, 1991a) some of these suggestions were examined further.

Hurrell and Vincent (1990) used FGGE Level III-b analyses from GLA to investigate the changes noted above and to diagnose the relationship between tropical heating and subtropical wind maxima during SOP-1 in the Southern Hemisphere. We examined day-to-day variations in the flow and also composited the results for two 15-day periods. In Period 1 (6-20 January), the central South Pacific was extremely active convectively, while in Period 2 (3-17 February), convective activity over the western Indian Ocean was enhanced. Episodes of strong outflow in the tropics, as measured by the upper tropospheric velocity potential, were found to be well correlated with the strengthening and propagation of westerly wind maxima in the subtropics. The average location of the westerly maximum over the South Pacific and Indian oceans was about 16° latitude south, and slightly east, of its corresponding heat source. For a cyclone case study which was presented, however, this distance was considerably less. The response time between the upper level tropical outflow and subtropical westerly enhancement appeared to be less than 12 hours; however, an exact temporal scale was difficult to identify.

Hurrell and Vincent (1991a) conducted an additional investigation of the potential causes for the observed subtropical wind maxima noted above. In addition to the forcing from tropical divergent flow, the importance of middle latitude forcing was examined through the use of the localized Eliassen-Palm flux equations. Also, the interaction of divergent and rotational flows in the subtropics was analyzed using the complete kinetic energy budget, partitioned into rotational and divergent components.

Throughout the summertime subtropics, it was generally found that the dominant term in the zonal momentum budget was the Coriolis force applied to the diabatically-driven meridional circulation. The largest positive tendencies due to this term were found in the entrance regions of the subtropical westerly maxima, and divergent circulations accounted for nearly all of the total ageostrophic flow. In the SPCZ region, however, it was found that transient eddies played an important role by partially offsetting the strong Coriolis acceleration in the entrance region of the local jet, and they helped accelerate the westerly flow in the exit region through both barotropic and baroclinic processes. Energetically, the dominant term in the rotational kinetic energy budget throughout the subtropical belt was the conversion of divergent to rotational kinetic energy. Furthermore, nearly all of the generated divergent kinetic energy was converted. The evidence from all of these approaches supports the view that tropical heating in transient events drives or enhances local meridional overturning in the atmosphere which, in turn, strengthens the summer subtropical westerly jet stream.

Robertson, et al. (1989) used ECMWF Level III-b analyses from FGGE to conduct a detailed investigation of the 4-dimensional structure of the SPCZ during a period (10-18 January 1979) when two cyclones formed in the tropics and propagated southeastward along the SPCZ into middle latitudes. During this period, the atmosphere was characterized by a highly baroclinic state

which, together with the existence of an upper troposphere subtropical jet, referred to above, supported the growth and development of the observed cyclone activity. The goal of our study was to examine the significance of kinematic and thermodynamic processes in maintaining the upper baroclinic region coincident with the subtropical jet. The baroclinic zone was just poleward of the warm core associated with the convectively-active SPCZ. A partitioned form of the frontogenetical function was used to diagnose the adiabatic and diabatic contributions to the maintenance of baroclinicity in the vicinity of the SPCZ. A major balance was found between the frontogenetical contribution by differential diabatic heating and the opposing diabatic tilting processes. In contrast to the results of most mid-latitude cyclone studies, the adiabatic contributions from the deformation and tilting terms appeared to be of lesser importance. Also, the contribution from the deformation associated with the horizontal branch of the diabatically forced circulation was found to be relatively unimportant. The latter finding is in disagreement with some previously reported numerical results concerned with middle latitude moist frontogenesis.

One of the suggestions made by Huang and Vincent (1988) was that the intraseasonal (40-50 day) oscillation in tropical convection may have been responsible for the observed enhanced convective activity in the SPCZ in January 1979 and its reduction and subsequent shift to the Indian Ocean region in February 1979. Thus, we decided to conduct an in-depth look at the intraseasonal oscillation. We focused our attention on the period, May 1984 - April 1986, which coincided with part of the period of our precipitation studies referred to in section 3a. The results of this study are reported by Vincent, *et al.* (1991b) who used ECMWF analyses to examine the variation of convective activity over the Southern Hemisphere from 0-15°S. The initial period investigated was 1 May 1984 - 30 April 1986. This diagnosis revealed that the oscillation was essentially absent in the Southern Hemisphere during the winter months. Therefore, the paper focused on two subperiods, 1 November 1984 - 30 April 1985 (Year 1) and 1 September 1985 - 15 April 1986 (Year 2), when the oscillation could be detected. Although several variables were examined, the velocity potential at 200 mb (χ_2) and outgoing longwave radiation (OLR) were found to be the best indicators of the oscillatory convective activity; consequently, these variables were the only ones presented. One of the unique features of this study was that the data were not temporally filtered, except for removing the time mean and linear trend, until after it was established that statistically significant peaks occurred on the intraseasonal time scale. This was an important step in this case because the dominant spectral peaks for the oscillation in each year were considerably different. In Year 1 the significant intraseasonal period was between 50 and 67 days, while in Year 2 it was centered near 33 days. Based on this, a recursive bandpass filter of 40-80 days was applied to Year 1 and 27-44 days to Year 2. If the data had been temporally filtered at the onset (e.g., 30-60 day band pass), the proper conclusions may not have been reached.

For the most part, our findings agreed with those of previous investigators. The oscillation propagated eastward, and its convective activity in both years was more intense over the Indian Ocean-Indonesia-western Pacific region than elsewhere. Furthermore, the χ_2 -wave could be followed continually around the globe, but the convection (OLR) associated with the oscillation was weak and difficult to track over much of the Western Hemisphere. The primary difference between the two years, besides the period

of oscillation, was that the correlation between x_2 and OLR was much greater in Year 1.

c. General circulation modeling of low latitude circulations

In support of our observational studies of the relationship between tropical heating and subtropical wind maxima, we recently began to conduct general circulation modeling experiments using the GLA GCM. In 1989, with assistance from personnel at GSFC and Purdue University Computing Center (PUCC), Dr. Hurrell successfully ported the GCM for use on Purdue's computing system. In the last 1 1/2 years, we have conducted a number of experiments with the model. Our results are discussed in Hurrell and Vincent (1991b, 1992). As noted above, the main emphasis of these papers was to better understand the relationship between tropical heating and subtropical wind maxima. We focused on a 15-day period, 6-20 January 1979, when our observational results suggested that strong convection over the South Pacific was helping to maintain a nearby subtropical jet. A "full physics" control integration was initialized on 4 January and run out to 20 January. Time averages of several variables were then compiled and examined for 6-20 January. The two day lead time for initialization was needed to bring the model's hydrological cycle into balance. The control run was able to reproduce the observed heating associated with the tropical portion of the SPCZ, as well as the zonal wind maximum in the adjacent subtropics.

To examine the importance of direct meridional overturning on the rotational flow in the subtropics, the latent energy supplied to the atmosphere was altered in two ways. First, negative sea surface temperature (SST) anomalies were imposed in the area of observed maximum convection. Three different simulations of SST anomalies were attempted. In the first (SST1), the largest reduction was 2°C at the center of the heat source, while in the second (SST2) and third (SST3) simulations the imposed anomalies were 1.5 and 2 times those in SST1. We found that the first simulation was sufficient to produce the desired result, namely, there was a strong reduction in the divergent outflow from the heat source into the entrance region of the subtropical jet. Moreover, this resulted in a reduction by a factor of two in the speed of the jet. Elsewhere, the response in the zonal wind to the reduced heating consisted of Rossby wave pockets emanating from the region of maximum heating in the control run. This circulation pattern was in agreement with the findings of several previous studies using simpler models.

The second way in which latent energy of the atmosphere was altered was by ignoring temperature changes due to precipitation processes in the model thermodynamic equation. This approach has been more widely applied in investigations of this nature, especially in studies that have utilized the GLA GCM. In this study, it was decided to eliminate the temperature changes due to both supersaturation and convective precipitation. For consistency, temperature changes due to evaporation of falling precipitation were also neglected. Two simulations were run, one where temperature changes were suppressed over the total tropics (NTLH) and the other where they were suppressed in the vicinity of the SPCZ region (NRLH), as was the case for the SST anomaly experiments. The impact of NRLH was similar to SST1 but the circulation changes appeared to be too drastic; thus, only the results of NTLH will be summarized. Unlike the localized impact seen in SST1, the more global

approach of NTLH essentially eliminated the 200 mb divergence throughout the tropics. Apparently, these strong changes in the divergent wind field were responsible for equally dramatic differences in the rotational zonal wind (u_y). Furthermore, a significant reduction of u_y occurred throughout the subtropics, including maximum decreases in excess of 25 ms^{-1} in the vicinity of the SPCZ westerly maximum and in the regions of the three climatological wintertime jet cores in the Northern Hemisphere. The equality of the decreases in both hemispheres emphasizes, in relative terms, the importance of tropical heating to the maintenance of the weaker summertime subtropical westerly maxima (i.e., the thermal gradients in the Southern Hemisphere subtropics were almost entirely eliminated). The fact that changes in u_y are stronger and more global than those in SST1 was merely due to the severity of the changes made to the model physics in NTLH (i.e., in SST1 the heating was slowly reduced over a local area as a result of the imposition of negative SST's).

It is revealing to contrast the time-response of the divergent and rotational circulations in NTLH to those in SST1. Examinations of 12-hour model output fields revealed that, unlike SST1, the divergent circulations reacted to the reduced tropical latent heating within half a day of the beginning of the experiment. Apparently, as suggested by other investigators, this time response indicates that the divergent wind is adjusted by rapidly propagating gravity waves and may, therefore, be quickly modified by changes in tropical heating. The response of the rotational wind in the Southern Hemisphere subtropics, and in the SPCZ region in particular, appeared to be in phase with changes in the poleward component of divergent flow (v_x) (i.e., the response was almost immediate). Outside of the Southern Hemisphere subtropics, however, the impact of the reduced latent heating was felt in u_y approximately 2-3 days after the beginning of the experiment, in good agreement with the results of others. The more immediate response of the rotational flow in the summer subtropical belt might have been a result of the asymmetric distribution of the heating about the equator. It was also in excellent agreement with the observed short-time response of the subtropical zonal wind to changes in v_x discussed by Hurrell and Vincent (1990).

4. CONCLUSIONS AND RECOMMENDATIONS

With regard to our first research goal, i.e., heat and moisture budget studies in the tropics, we conclude that our formulation of the Q_1 -budget method yields sufficiently accurate estimates of precipitation over tropical oceans on monthly time scales and regional (e.g., 20° lat/lon) space scales. Currently, we are working on two tasks which we believe will result in improved rainfall estimates. First, one of our Ph.D. students (Mr. Ramsey) is using ISCCP data (Ramsey, 1990), together with an established radiation model to derive vertical profiles of radiation. Previously, as noted in Vincent, et al. (1991a), we have assumed constant values for all radiative components, except outgoing longwave radiation (OLR). Mr. Ramsey's research will allow us to derive vertical profiles of convective heating and should make it possible to obtain precipitation estimates on shorter-than monthly time and regional space scales. Second, another Ph.D. student (Mr. Bourassa) is conducting research on obtaining reliable estimates of evaporation over the tropical oceans using conventional data. His goal is to use the Q_2 -budget approach to

derive values of precipitation rates and to compare them with our Q_1 -budget estimates.

For our second research goal, we conclude that poleward moving divergent air in the upper tropical troposphere can play an important role in the direct thermodynamic forcing of subtropical wind maxima, at least in the Southern Hemisphere during summer. However, our conclusion is based on only one case study which utilized the highly specialized FGGE data set. Also, we speculate that the intraseasonal oscillation might be important in enhancing the divergent outflow. Therefore, we recommend that additional studies be conducted to answer the following three questions: (1) Is the relationship between tropical heating and subtropical wind maxima a regular feature of the circulation patterns over the South Pacific?; (2) If so, can it be detected using a routine data set?; and (3) How important is the intraseasonal oscillation in causing the enhanced outflow? Presently, we are conducting an investigation to answer these questions. Preliminary results of 8 cases of wind maxima over the South Pacific, based on using ECMWF analyses during the summer season of 1984-85, reveal that poleward divergent outflow from the tropics was a maximum near the entrance region of the observed local wind maximum in each case. Each wind maximum persisted from 1-2 weeks and, in general, propagated slowly eastward. Four of the cases appeared to occur in the convectively-active phase of the oscillation, while four did not. As expected, the poleward divergent flow was stronger when the oscillation was in its active phase. There was no substantial difference, however, in the average zonal wind speed between oscillation and non-oscillation cases. We now speculate that other mechanisms might be responsible for decelerating the zonal wind in its entrance region during the oscillation cases, and we plan further examinations of this aspect of the problem.

As for our second research goal, the conclusions reached with regard to our third goal (i.e., GCM studies of low latitude circulations) are based primarily on one case study, again using FGGE analyses as initial input. Thus, we feel that additional numerical investigations should be undertaken to quantify the role of tropical heating on causing and maintaining subtropical wind maxima. The respective roles of gravity and Rossby wave propagation were only inferred from our GCM study. It would be of interest to separate the winds into their Rossby and inertia-gravity modes. Also, we feel that a larger number of integrations with perturbed initial conditions should be obtained in order to determine the natural variability (with respect to short and medium range forecasting) of the version of the GLA GCM used by us. This is desirable to statistically document the significance of results from experimental integrations performed with modified model physics.